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Irrigated Corn Yield Response to Nitrogen and Water[1]

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ABSTRACT

Irrigated corn (*Zea mays* L.) is a relatively new crop on the Southern High Plains where the groundwater supply for irrigation is declining. Field studies were conducted to determine the plant nutrient needs for corn on a predominant soil of the area, the effects of timing and duration of drought stress periods, and the interacting effects of N levels and drought stress on N nutrition and production of corn. Fertilizer N rates ranged from 0 to 350 kg/ha. Irrigations were applied or deleted to allow the crop to be unstressed (I-1), stressed 2 weeks during late vegetative growth (I-2), stressed 2 weeks during early vegetative growth (I-2a), stressed 4 weeks during vegetative growth (I-3), stressed about 4 weeks during grain filling (I-4), and stressed about 2 weeks during grain filling (I-5). The soil was Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls). Four-year average data (three with graded furrow irrigation, one in level borders) showed that 140 kg N/ha were sufficient for maximum yields. However, simultaneous experiments conducted on graded furrows and level borders showed that while 140 kg N/ha gave maximum yields on graded furrows, 210 kg N/ha were required in level borders. This comparison illustrates the possible fallacy in conducting fertilizer trials under one method of irrigation and extrapolating results to another. Two and 4 weeks of plant water stress during vegetative growth reduced yields of adequately fertilized (210 kg N/ha) corn 23 and 46%, respectively. Two-week stress periods during late (I-2) and early (I-2a) vegetative growth had similar effects on grain yields. Relationships between lengths of stress periods during grain filling and yield showed that yields were reduced 1.2% for each day stress was imposed during grain filling; however, as indicated by the r^2 (0.31), there was considerable variation in the data. A N × water stress interaction occurred on grain yields. Adequate N slightly increased corn grain yield under stress and greatly increased yield with full irrigation. Excessive N did not reduce yield even with severe water stress, thus, there would be no reason to reduce N rates to reduce water stress. As grain yields increased, the ratio of grain yield to N yield decreased until maximum yields were attained and then remained constant, indicating little luxury consumption of N. At maximum yield, typical grain yield/N yield ratios were about 52:1. At harvest soil NO_3^--N levels showed that plants had removed most of the N applied at rates up to 140 kg/ha, but increasing amounts remained when N application rates were above 140 kg/ha.

***Additional index words:* *Zea mays* L., Plant water stress, Yield components, Grain yield:N yield ratio, Irrigation methods.**

FROM 1966 to 1976, the area of irrigated corn (*Zea mays* L.) in the Southern High Plains increased from approximately 25,000 to over 500,000 ha. Research involving corn production in the region was limited. Although the plant nutrient needs for corn were known (8), application rates to supply those needs had not been determined with Southern High Plains conditions and soils. Fertilizer recommendations were often based on fertility trials with grain sorghum [*Sorghum bicolor* (L.) Moench]. This increase in hectarage of corn occurred in an area where the groundwater supply available for irrigation is limited. The water level in the Ogallala Aquifer, the principal irrigation water supply for the area, is declining at a rate of 0.6 to 1 m/year (9). Groundwater depletion and increasing pumping costs emphasize the need for conservation and efficient use of water.

Limited irrigation—applying less water than is required to meet potential evapotranspiration (ET)—is extensively practiced on the drought tolerant crops of grain sorghum, wheat (*Triticum aestivum* L.), and cotton (*Gossypium hirsutum* L.) (9). Reduced water application permits continued irrigation of most of the cropland in existing systems. With drought tolerant crops and significant seasonal rainfall, water-use efficiency is often increased with limited irrigation. It is well established that water stress during pollination can have a disastrous effect on corn grain yields but the effects of stress at other growth stages are less drastic.

At Prosser, Wash., Robins and Domingo (12) found that depletion of soil water to the wilting point for 1 or 2 days during tasseling or pollination resulted in a 22% yield reduction. Six to 8 days of stress at that growth stage reduced yields 50%. In Iowa, Denmead and Shaw (4) found that water stress prior to silking reduced grain yield by 50% and water stress after silking reduced grain yields by 21%. At Scottsbluff, Nebr., Howe and Rhoades (5) found that water applied to maintain a low soil water tension during the stage of growth before tasseling through silking was used more efficiently than that applied later in the season. At Etter, Tex., Shipley and Regier (15) found that 14 days of plant water stress beginning at tasseling reduced yields 39% while equivalent periods of stress beginning 14 days before or 14 days after tasseling or during milk stage reduced yields an average of 17%. At Bushland, Tex., Musick and Dusek (9) found that stress during tasseling and silking was most harmful and that stress during grain filling was more harmful than that during vegetative growth.

Although the literature contains numerous reports of fertilizer trials and irrigation studies with corn, there are comparatively few in which both irrigation and fertilization have been studied. Nitrogen fertilizer increases water-use efficiency on N deficient soils when water is adequate (3, 10, 18) but less is known of the effects of high rates of N when water is limiting. In Wyoming, Burman et al. (2) found that 70 kg N/ha were sufficient for maximum yield on a dry treatment while additional response was obtained from 140 kg N/ha on wetter treatments, however, the additional N did not decrease yield on the dry treatment. They concluded that there was no consistent change in the number of irrigations required to maintain desired soil water conditions because of N fertilizer levels. In Utah, Bauder et al. (1) experienced decreased dry matter yields of corn from N rates in excess of 200 kg/ha on low water level treatments. In Nebraska, Russelle et al. (13) conducted an irrigation-N fertilizer study and obtained maximum grain yields at about 150 kg N/ha on all irrigation treatments. Irrigation treatment-induced yield differences were comparatively small.

The objectives of this study were to determine (1) the plant nutrient needs for sustained high levels of

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corn production on Pullman clay loam (fine, mixed, thermic Torrertic Paleustolls) (16); (2) the effects of timing and duration of drought stress periods on N nutrition and production of corn; and (3) the interacting effects of N levels and drought stress levels on N nutrition and production of corn.

MATERIALS AND METHODS

The studies were conducted on Pullman clay loam at the USDA Conservation and Production Research Laboratory, Bushland, Tex. The moderately permeable surface soil (0 to 0.2 m) is underlain by a dense, very slowly permeable montmorillonitic clay horizon (B22t) extending from the 0.2- through the 0.5- to 0.6-m depth. Below this depth, the soil is somewhat more permeable. Depth to the highly calcareous "caliche" layer ranges from 1.2 to 1.5 m. At −0.034 and −1.5 MPa matric potential the soil contains approximately 0.43 and 0.27 m of water, respectively, in the top 1.2 m of the profile.

A 3-year study was conducted under graded furrow irrigation on an area with about 1% slope and two 1-year studies were conducted in level borders on a slightly sloping area (before leveling). To remove accumulated N, both sites were cropped to irrigated silage corn in years immediately preceding initiation of experiments. The site on graded furrows contained 58 kg NO_3^--N/ha in the surface 1.2 m at the initiation of the experiment in 1976. That of the 1979 study on level borders had an initial NO_3^--N level of 24 kg/ha in the surface 1.2 m. The initial NO_3^--N level in one-half (two replicates) of the 1978 study on level borders was 27 kg/ha. The other two replicates occupied plots which had been in a similar study in 1977 and had contained 43 kg NO_3^--N/ha in the surface 1.2 m at the beginning of that study. Treatments imposed in 1977 were repeated on the same plots in 1978. Results of the 1977 study are not reported here.

In the study on graded furrows, corn was grown under eight fertilizer treatments and five irrigation regimes. Fertilizer treatments applied in 1976 were N at rates of 0, 70, 140, 210, 280, and 350 kg/ha (treatments 1 through 6), 350 kg N/ha plus 40 kg P/ha (treatment 7), and 350 kg N/ha plus 40 kg P/ha plus 15 kg Zn/ha (treatment 8). Soil tests after the 1976 crop indicated that, at N rates in excess of 210 kg/ha, considerable NO_3^--N remained in the soil. So in 1977, the planned N applications were made (as in 1976) on treatments 1 through 4 but on treatments 5 through 8, only 210 kg N/ha were applied. In 1978, N was applied at the design rates applied in 1976.

Irrigation dates are presented in Table 1. Irrigations were spaced to allow the crop to be unstressed (I-1), stressed 2 weeks during late vegetative growth (I-2), stressed 2 weeks during early vegetative growth (I-2a), stressed 4 weeks during vegetative growth (I-3), stressed 4 weeks during grain filling (I-4), and stressed 2 weeks during grain filling (I-5). Treatment I-2a was studied in 1976 and 1978 and I-3 was studied in 1977.

The irrigation schedule for I-1 was based on prior experience. Frequency and amounts applied were such that no recognizable yield-depressing stresses were encountered. Stresses were imposed on the other treatments by leaving off one or two of the irrigations scheduled for I-1. We attempted to better quantify stress with measurements of afternoon leaf water potential with a pressure chamber (14) but we found only small differences between stressed and unstressed plants (data not shown). Apparently, stomatal closure limited water loss, thus decline of leaf water potential under stress.

The experiment had a randomized block-split plot design with four replications. Main plots were 9.1 × 91.4 m and subplots were 4.5 × 22.9 m. Irrigation treatments occupied main plots and fertilizer treatments occupied subplots. Subplots contained six rows of corn that were 0.76 m apart.

Following fertilizer application each year, the site was uniformly preplant-irrigated. Both preplant and seasonal irrigation water was applied through gated pipe and measured to individual furrows with the bucket and stopwatch technique. In 1976, the application rate was 38 L min^{-1} $furrow^{-1}$ and, in 1977 and 1978, it was 23 L $min^{-1}furrow^{-1}$. Tailwater runoff of 3- to 6-h duration was measured from five furrows per plot through 0.3-m precalibrated H-flumes equipped with water stage recorders. Water infiltration was determined as the difference between application and runoff.

Studies were conducted in level borders in 1978 and 1979. In both years, N rates were 0, 70, 140, 210, 280, and 350 kg/ha (treatments 1 through 6 as on the graded furrow study). In 1979, two P treatments of 20 and 40 kg/ha were added, each in combination with 210 kg N/ha. Seasonal irrigation dates are presented in Table 1. Irrigation treatments were similar to those studied for graded furrows except I-3 was studied in both years and I-2a was not used. Water was applied through gated pipe and metered to individual plots. Like the graded furrow experiment, these studies had randomized block-split plot designs with four replications. Irrigation treatments occupied main plots and fertilizer treatments occupied subplots. In 1978, main plots were 12.2 × 46 m and in 1979, they were 12.2 × 61 m. Subplots were 6.1 × 15.2 m in both years and contained eight rows of corn that were 0.76 m apart. Plots were maintained in beds and furrows for uniform water distribution.

In both the graded furrow and level border studies, fertilizer was broadcast on the surface and incorporated with a sweep-rodweeder or a rolling cultivator prior to preplant irrigation, which was applied about 30 days before planting. Fertilizer materials were ammonium nitrate (33-0-0), concentrated superphosphate, and zinc sulfate.

Planting was on 28 Apr. 1976, 6 May 1977, 1 (graded furrows) and 12 May (level borders) 1978, and 10 May 1979.

Table 1. Irrigation treatments and dates, seasonal irrigation water applied, and seasonal ET.

	Irrigation dates							
Treatment	Vegetative		Pollination	Grain filling			Irrigation	ET
1976	6/14	6/28	7/12	7/28	8/11	8/27	mm	
I-1	x	x	x	x	x	x	685	937
I-2	x		x	x	x	x	567	845
I-2a		x	x	x	x	x	582	846
I-4	x	x	x				332	641
I-5	x	x	x	x			451	757
1977	6/16	7/5	7/19	8/4				
I-1	x	x	x	x			659	984
I-2	x		x	x			481	805
I-3			x	x			341	682
I-4	x	x	x	x			659	994
I-5	x	x	x	x			659	1003
1978	6/29	7/13	7/25	8/8	8/23	9/5		
I-1	x	x	x	x	x	x	717	970
I-2	x		x	x	x	x	576	850
I-2a		x	x	x	x	x	579	845
I-4	x	x	x	x			505	781
I-5	x	x	x	x	x		634	905
1978 (level borders)	6/30	7/12	7/26	8/15	8/28	9/11		
I-1	x	x	x	x	x	x	635	884
I-2	x		x	x	x	x	533	772
I-3			x	x	x	x	406	648
I-4	x	x	x	x			432	676
I-5	x	x	x	x	x		533	789
1979	6/28	7/13	7/26	8½15		9/4		
I-1	x	x	x	x		x	500	783
I-2	x		x	x		x	400	693
I-3			x	x		x	300	572
I-4	x	x	x				300	631
I-5	x	x	x	x			400	710

Corn hybrids grown were 'Pioneer 3369A' in 1976 and 'Pioneer 3184' in all other years. Plant populations averaged 8.6 plants/m² in 1976 and 6.0 in the other years.

Seasonal ET was determined from a water balance using beginning and end of season soil water sampled to a 1.8 m depth and seasonal irrigation and rainfall. Seasonal rainfall and nearby weather station air temperatures are shown in Fig. 1.

Samples for grain yield determination were hand harvested from a 14-m² area of each plot, shelled, and adjusted to 16% grain moisture. Forage yields were determined from single 0.76 m² areas of each plot. Samples were separated into leaves, stalks, and grain, then oven-dried at 60 °C. Forage yields include leaves, stalks, and cobs. Subsamples of leaves, stalks, and grain were ground in a Wiley mill and analyzed for total N by the method of Thomas et al. (17).

Residual NO_3^--N was measured in the upper 1.8 m of soil after harvest each year. Samples were taken at 0.3-m depth increments from three locations per fertilizer plot and composited by depth increments. Nitrate-N was extracted by 0.1 *N* KCl and determined with an autoanalyzer (7).

Five hundred oven-dried seeds were counted and weighed to determine seed weights. Seeds/m² were calculated from seed weights and yields of oven-dried grain.

Analyses of variance were calculated for the randomized block with a split plot for N levels. Linear, quadratic, and cubic effects of N level and N-level interaction with water-stress treatments were tested. Effects were judged significant at the 0.05 level. After it was determined that the P and Zn treatments did not affect yields, they were excluded from the analyses. Second order polynomial regressions were fitted with grain yield, N in the plant and NO_3^--N in the soil as dependent variables, and kg of fertilizer N as the independent variable for each year, irrigation method, and water-stress level.

RESULTS AND DISCUSSION

Fertilizer needs. The effects of N rates on grain yields on the adequately watered treatment (I-1) are shown in Fig. 2. Yields from each of the 3 years on the graded furrow site show that maximum or near maximum yields were obtained with the 140 kg N/ha rate, however, response was obtained to higher N rates on the level bordered site. Near maximum yields were obtained from 210 and 280 kg N/ha in 1978 and 1979, respectively. Comparison of the curves for graded furrows and level borders in 1978 show that yields on check plots were lower and N response continued through 210 kg N/ha on the level bordered site. Also, visual observation indicated that the N status of plants on check plots at the level bordered site was poorer

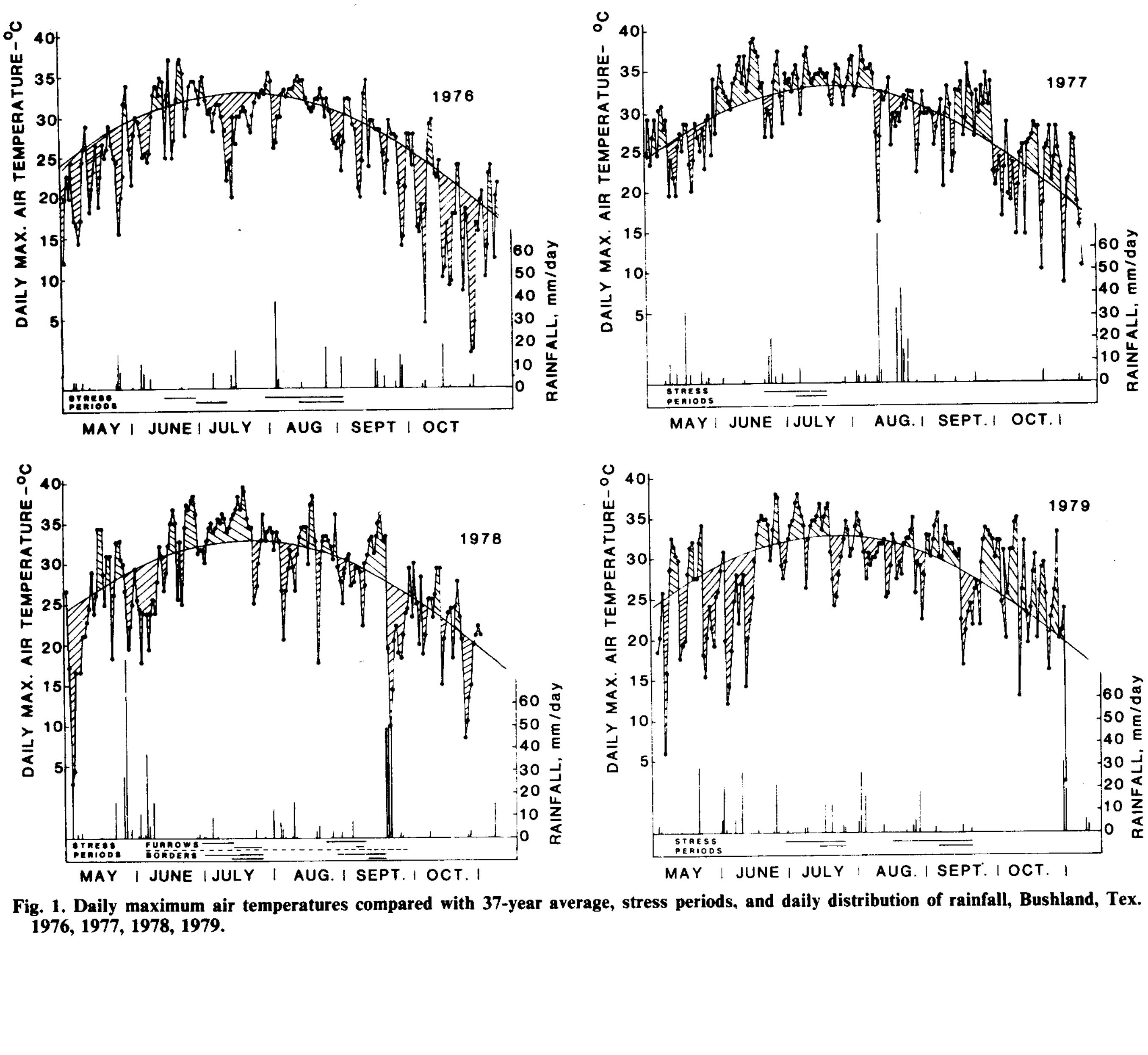

Fig. 1. Daily maximum air temperatures compared with 37-year average, stress periods, and daily distribution of rainfall, Bushland, Tex. 1976, 1977, 1978, 1979.

than that of those at the graded furrow site. Soils on the two sites are similar. Residual NO_3^--N levels (to 1.2 m) in November 1977 were not significantly different on similarly treated plots (N rates through 210 kg/ha) on the two sites and again at the end of the 1978 season, NO_3^--N levels were similar on those similarly treated plots (data not shown). The reason for the difference in N response between the two sites is not readily apparent. It may be due to some denitrification on the level bordered site since the plots were inundated at irrigation and some water remained on the surface for about 24 h after irrigation. This comparison illustrates a possible fallacy in conducting fertilizer trials under one method of irrigation and extrapolating results to another.

Corn did not respond to P or Zn on this soil (data not shown). Although soil tests indicate that P was low (5 ppm NH_4OAc-extractable), yield responses to P have not been obtained on other field crops (6, 11). The soil contained 1.6 ppm extractable Zn. No evidence of Zn deficiency was observed in any of the experiments.

Plant Water Stress Effects. Because of interactions, yields are presented by years and N and water stress treatments. Parameters of equations for summary curves are not presented because they do not have predictive values from year to year. Data from 3-years (1977 on graded furrows, 1978 and 1979 on level borders) are available for determining effects of 2 and 4 weeks of stress during vegetative growth on yields (Table 2 and Fig. 3). Two and 4 weeks of stress reduced yield of adequately fertilized (210 kg N/ha) corn by 23 and 46%, respectively. Data from individual years show that equivalent stress periods affected yields considerably more in some years than in others. The greatest effect was in 1978 when average yield depressions for the 2- and 4-week stress periods were 28 and 71%, respectively. The smallest effect occurred in 1979 when reductions on the respective treatments were only 9 and 17%. Climatic conditions during stress periods undoubtedly affected the severity of stress effects. A sustained period with above average maximum air temperatures occurred during stress periods in 1978, while in 1977 and 1979, maximum temperatures were not as consistently high as those in 1978 and there were more days with below average temperatures (Fig. 1). Also, in 1979, a period of consistently below average temperatures occurred during the last week of the 4-week stress period. Rainfall was scant during

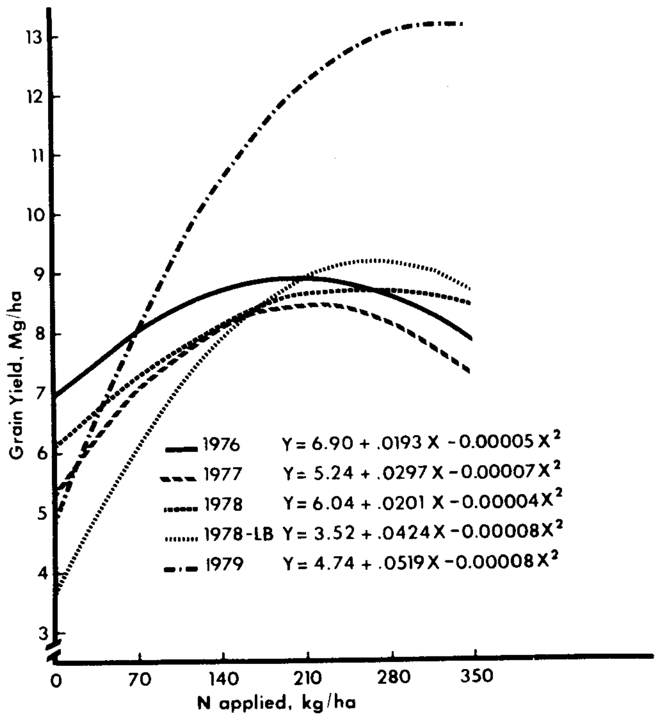

Fig. 2. Grain yields as affected by N rates, adequately watered treatment.

Table 2. Grain yields as affected by plant water stress during vegetative growth and N treatments, 1977 (graded furrows), 1978 and 1979 (level borders).

Nitrogen rate	1977 Stress treatment			1978 Stress treatment			1979 Stress treatment		
	I-1	I-2	I-3	I-1	I-2	I-3	I-1	I-2	I-3
kg/ha	Mg/ha								
0	4.89	5.03	3.24	3.55	2.88	1.79	4.20	3.47	3.71
70	7.45	5.95	3.19	6.09	5.17	3.19	8.97	7.96	7.74
140	8.40	5.51	3.08	7.93	6.02	3.22	10.53	10.07	8.64
210	8.27	5.18	3.47	8.66	6.24	2.53	11.22	10.20	9.26
280	7.51	5.19	3.63	9.55	5.72	2.56	13.15	11.78	8.75
350	7.66	5.35	3.64	8.49	5.68	3.41	13.21	10.96	7.98

coefficients relating yields to N treatments ($y = b_0 + b_1x + b_2x^2$)

	Irrigation treatment	b_0	b_1	b_2
1977	I-1	5.24	0.0297	−0.000069
	I-2	5.32	0.0021	−0.000007
	I-3	3.19	−0.0003	0.000005
1978	I-1	3.52	0.0424	−0.000079
	I-2	3.13	0.0283	−0.000062
	I-3	2.23	0.0063	−0.000012
1979	I-1	4.74	0.0519	−0.000080
	I-2	3.86	0.0566	−0.000105
	I-3	4.13	0.0480	−0.000108
Pooled	I-1	--	0.0414	−0.000076
	I-2	--	0.0290	−0.000058
	I-3	--	0.0180	−0.000038

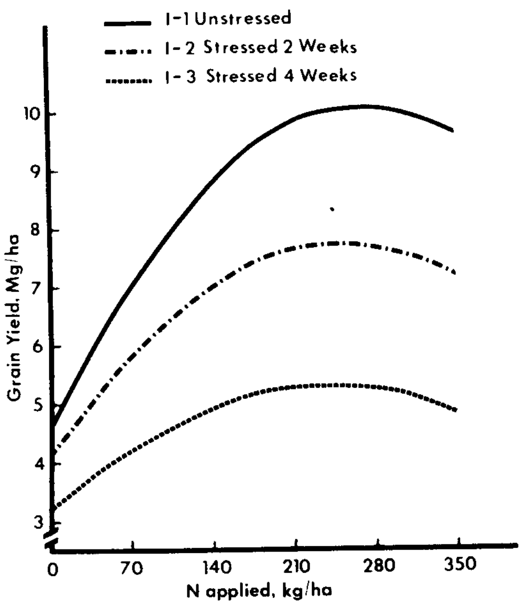

Fig. 3. Grain yields as affected by N rates and plant water stress during vegetative growth. Average 1977 (graded furrows), 1978 and 1979 (level borders).

vegetative stress periods in all three seasons, however, there was less rainfall during those periods in 1978 than in 1977 or 1979.

Two-year average data (1976 and 1978) from the graded furrow site show that 2 weeks of stress during early vegetative growth had about the same effect on grain yield as an equivalent stress period during late vegetative growth (Table 3 and Fig. 4).

Data from four harvests (1976 and 1978 on graded furrows, 1978 and 1979 in level borders) are available for studying effects of stress during grain filling on yields (Fig. 5). Stress periods during grain filling were more variable in length than those during vegetative growth. When corn plants are severely stressed after pollination, maturity is advanced and even when stress is relieved, recovery is limited. Thus, treatments were designed to impose stress during the final 2 and 4 weeks of the grain-filling period. Influence of previous seasonal irrigations and precipitation prevented uniform imposition of stress periods from year to year. Pioneer '3369A' (grown in 1976) has an approximate growing period of 125 days (days to black layer), while it is 131 days for '3184' (grown after 1976). For Treatment I-4, stress was imposed 91 days after planting in 1976, 108 and 114 days after planting in 1978 (level borders and graded furrows, respectively) and 97 days after planting in 1979. For treatments 4 and 5, stress was not imposed in 1977 due to precipitation. Since the stress periods extended to maturity in each case, treatment effects during grain filling caused a shortening of the grain-filling period. Using the approximate growing periods and dates of stress initiation, number of days before normal maturity that stress was imposed on Treatment I-4 were 34 in 1976, 23 and 17 in 1978; and 34 in 1979. Using the same rationale for Treatment I-5, number of days before normal maturity that stress was imposed were 20, 10 and 2, and 14, respectively. This parameter is plotted against percent yield reduction in Fig. 6. A significant relationship was obtained ($r = 0.557$). Yields were reduced an average of 1.2% for each day stress was imposed before normal maturity. However, the coefficient of determination indicates that only about 31% of the variation in yield reduction was attributable to drought stress. Other sources of variation may have been (1) a thicker plant stand in 1976, (2) use of a different hybrid in 1976, (3) differences in methods of irrigation, and (4) differences in climatic conditions during stress period among years. Hybrid '3184' is rated more drought tolerant and as having better late season plant health than '3369A' (Jim Higdon, personal communication, Pioneer Hi-bred International, Inc., Plainview, Tex.). The thicker plant stand in 1976 would have caused stress to become more severe earlier and that stress may have been more severe in 1976 is evidenced by the fact that the interval between irrigations on I-1 (for first irrigation after stress was imposed on I-4) was 14 days in 1976 while in 1979, the interval for the same period was 20 days. Yield reductions were more severe when plants were grown on graded furrows than when they were grown in level borders. This may have resulted from more water being stored at deeper depths in level borders, and that extra water slowly becoming available to plants as their roots extended into it. The temperature data in Fig. 1 do not show differences to which the differences in stress effects can be attributed.

Fertilizer × Water Stress Interaction. The yield curves in Fig. 3 and 5 show an N × water stress interaction. At the lower N rates, N deficiency limited yields to the extent that water stress had only a small effect but with adequate or excessive N, water stress was the main yield-limiting factor. Although water stress reduced yields more with adequate than with deficient N, yield levels were higher on fertilized than on unfertilized treatments. The net effect was a response to N on all stress treatments. Also, excessive N did not enhance water stress. Thus, results obtained in these studies indicate that there would be no reason to reduce N application rates to reduce water stress effects.

Table 3. Grain yields as affected by plant water stress during early and late vegetative growth and N treatments 1976 and 1978 (graded furrows).

Nitrogen rate	1976 Stress treatment I-1	1976 I-2	1976 I-2a	1978 Stress treatment I-1	1978 I-2	1978 I-2a
kg/ha	Mg/ha					
0	7.02	5.20	6.29	5.98	5.65	6.62
70	7.74	7.54	7.49	6.99	6.72	7.12
140	8.74	8.33	8.20	8.94	7.37	6.40
210	9.13	8.39	8.36	8.29	7.57	6.66
280	8.38	9.45	8.71	8.15	6.85	7.45
350	7.90	9.15	10.00	8.77	7.42	7.56

Coefficients relating yields to N treatments ($y = b_0 + b_1x + b_2x^2$)

	Irrigation treatment	b_0	b_1	b_2
1976	I-1	6.90	0.0193	−0.000047
	I-2	5.47	0.0258	−0.000044
	I-2a	6.52	0.0104	−0.000004
1978	I-1	6.04	0.0201	−0.000038
	I-2	5.78	0.0141	−0.000029
	I-2a	6.78	−0.0028	0.000015
Pooled	I-1	--	0.0197	−0.000043
	I-2	--	0.0199	−0.000037
	I-2a	--	0.0038	0.000006

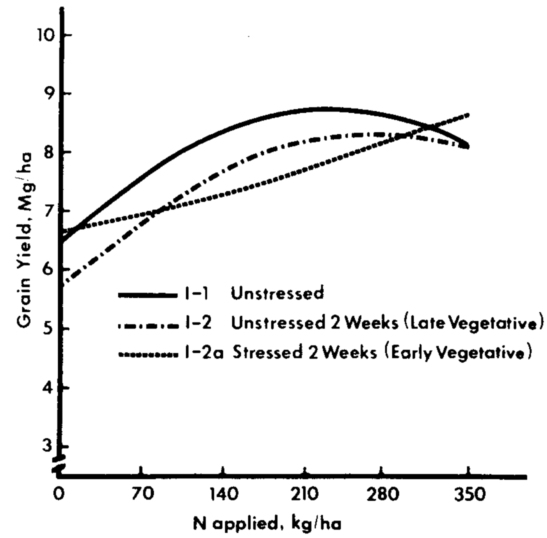

Fig. 4. Grain yields as affected by N rates and plant water stress during early and late vegetative growth. Average 1976 and 1978 (graded furrows).

Nitrogen and Plant Water Stress Effects on Yield Components. Seed number and seed weight data from the 1978 study on level borders (Fig. 7 and 8) are presented to illustrate the effects of treatments on those parameters. The major effect of N in increasing yields in all experiments was through increasing seed numbers. In the data shown, seed weight was also increased by N fertilization, however, in 1976 and 1977 on the adequately watered treatments, seed weights were significantly decreased at the higher rates of N. In 1978, in the graded furrows study, seed weights were not affected by N fertilization (data not shown).

Plant water stress during vegetative growth reduced yields through reducing seed numbers while, with one exception, reductions due to stress during grain filling were reflected in seed weight and not in seed numbers. The exception was the I-4 treatment in 1976 when both seed weight and seed numbers were reduced (data not shown). Apparently, the severe stress, beginning 34 days before normal maturity, halted filling of late-filling seeds when they were so immature that they were lost in shelling and seed cleaning. As stated previously, yield reductions from stress during grain filling were more severe in 1976 than they were in other years. The observed reactions to stress are logical since the number of fertile florets formed is determined during vegetative growth, while at grain filling, numbers of seeds have already been determined and stress affects the amount of filling that occurs.

Stress during vegetative growth, especially the I-2

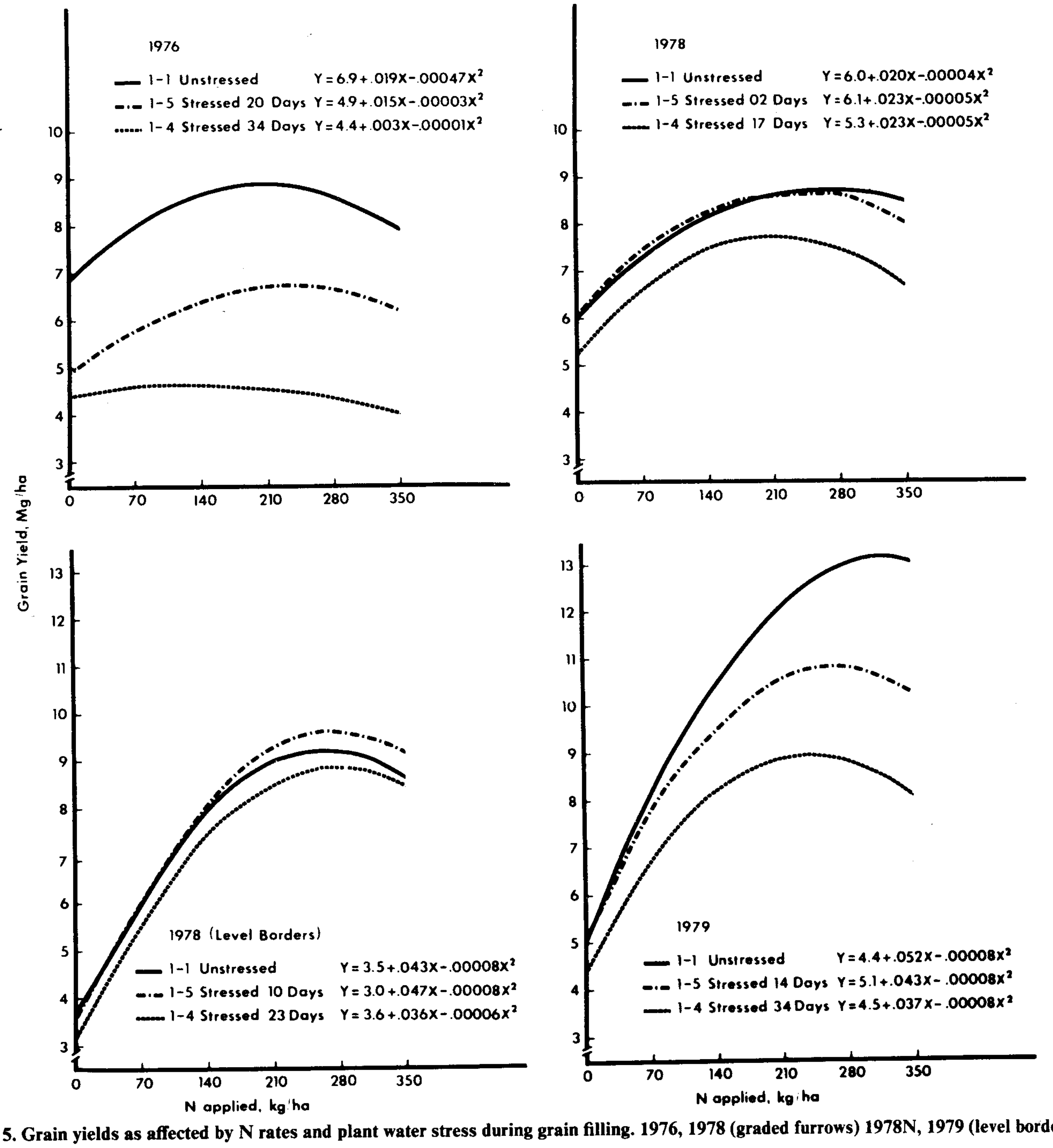

Fig. 5. Grain yields as affected by N rates and plant water stress during grain filling. 1976, 1978 (graded furrows) 1978N, 1979 (level borders).

treatment (Fig. 8) increased seed weight. This probably resulted from the number of seeds being reduced proportionately more than the reduction in leaf area, thus, there was more photosynthate available per seed on the I-2 treatment than on the unstressed treatment.

As with grain yields, stress-induced reductions in seed numbers and seed weights were proportionately greater at adequate or excessive N levels than at deficient N levels, giving significant fertilizer × water stress interactions. Even though drought stress effects were less severe with deficient N, these data, like the yield data, do not indicate that it would be advisable to reduce N rates to reduce water stress.

Nitrogen Yields and Residual N. Nitrogen yields (in the aboveground portion of the plants) are given for the 2 years in which planting time NO_3^--N levels were uniform on the sites. Since stress treatments did not significantly affect N yields, data are given for the I-1 treatment only. Data for first crops on the graded furrow (1976) and level bordered (1979) sites are given in Fig. 9. Nitrogen yields on the adequately irrigated treatment were maximum at the same N rates at which yields were maximum, indicating that there was little luxury consumption of N. However, the ratio of grain yield to N yield decreased as grain yields increased until maximum yields were attained and then remained relatively constant. In 1976, the unfertilized treatment produced 63 kg of grain for each kilogram of N uptake, while the N rate for maximum yield (210 kg/ha) produced 48 kg of grain for each kilogram of N yield. Comparable ratios for 1979 were 78:1 on the unfertilized treatment and 55:1 on the 350 kg N/ha treatment. The trends for ratios of grain to N yields to remain constant after maximum grain yields were attained were present on the stressed treatments but were less consistent than those on the unstressed treatments. The largest departure was on Treatment I-4 in 1976 where the ratios declined as N rates increased after maximum yield was attained. Apparently, the plants on the higher N treatments had accumulated N for grain yield levels that did not materialize because stress prematurely stopped grain filling before the N was utilized.

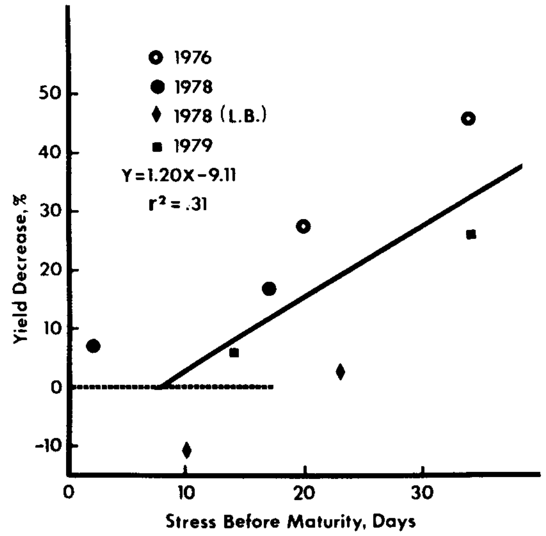

Fig. 6. Percent reduction in grain yield as a function of days of stress before physiological maturity (b_1 calculated from individual plots receiving 140 kg N/ha, treatment avgs. plotted).

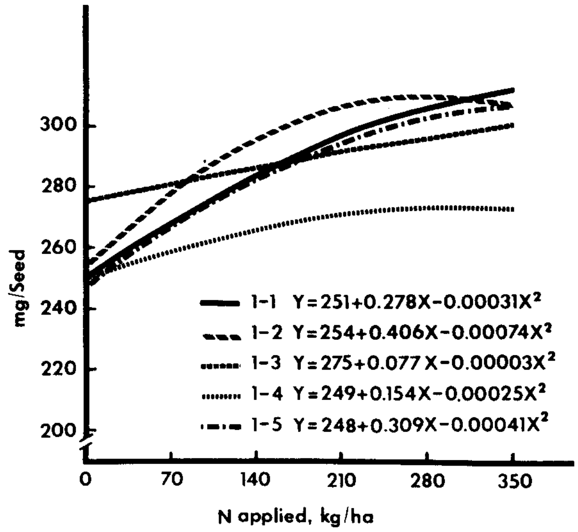

Fig. 8. Seed weights as affected by N rates and irrigation treatments, 1978 (level borders).

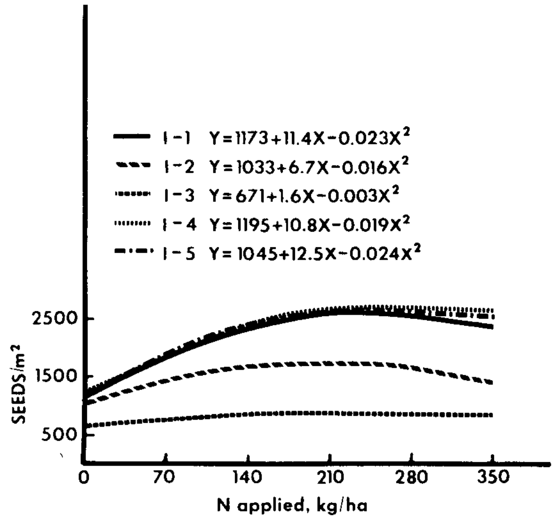

Fig. 7. Seed numbers as affected by N rates and irrigation treatments, 1978 (level borders).

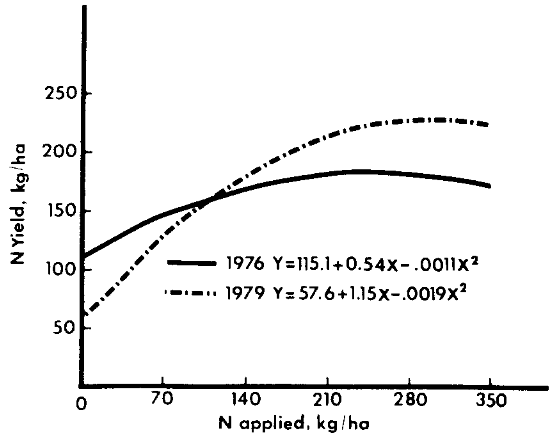

Fig. 9. Nitrogen yields as affected by N rates, unstressed treatment, 1976 and 1979.

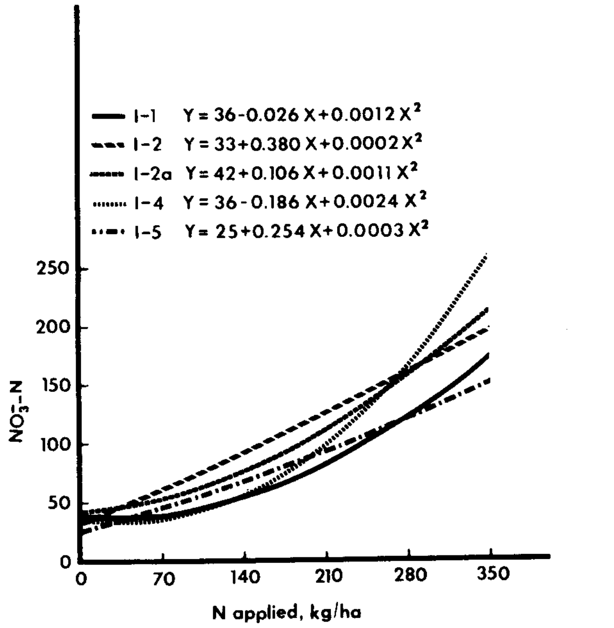

Fig. 10. Nitrate N to 1.2-m soil depth at harvest as affected by N rates and irrigation treatments, 1976.

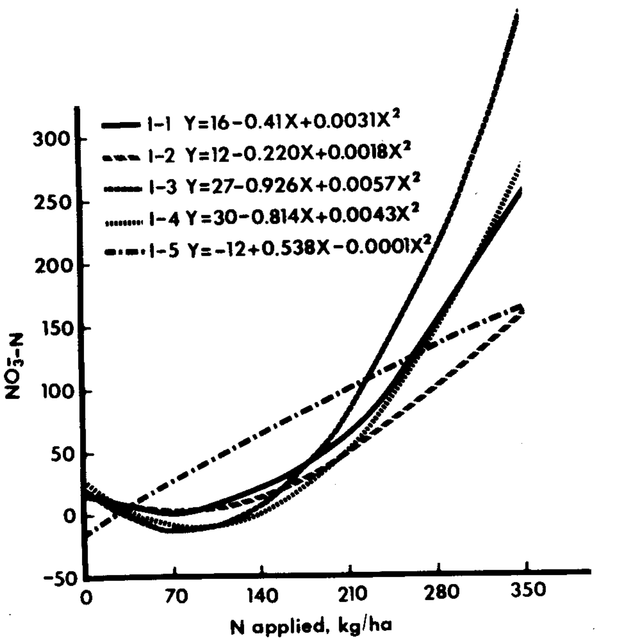

Fig. 11. Nitrate nitrogen to 1.2-m soil depth at harvest as affected by N rates and irrigation treatments, 1979.

Soil NO_3^--N levels after harvest (Fig. 10 and 11) show that plants removed most or all of the applied N from rates through 140 kg/ha but increasing amounts of residual N were present as N rates increased from 210 through 350 kg/ha. Differences between stress treatments were not significant, but because the interaction was significant, curves for N effects are given for each stress treatment. There was some inconsistency in the data but in general, the more severely stressed treatment plots contained more residual NO_3^--N than the adequately watered and less severely stressed plots. Residual NO_3^--N levels were noticeably higher on the lower N rate plots of the graded furrow site (1976) than on similarly fertilized plots on the level bordered site (1979). This is further evidence that higher N rates were required on the level bordered site. Initial NO_3^--N levels were higher on the graded furrow site (58 kg/ha in March 1976) than on the level bordered site (27 kg/ha in November 1978) which might account for some of the difference in residual N at the end of the season. However, with the greater N yields from the unfertilized treatments on the graded furrows, depletion to NO_3^--N levels nearer those on the level borders would be expected.

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